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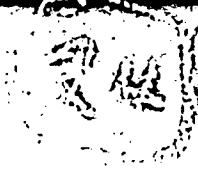## AUTHORITY

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# MASSACHUSETTS INSTITUTE OF TECHNOLOGY

## LINCOLN LABORATORY

# ELIMINATION OF A TYPE OF NATURAL CLUTTER
# IN L-BAND RADARS

(Title UNCLASSIFIED)

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## ABSTRACT

This report discusses an investigation of overwater, short-range, low-altitude targets observed on ground-based coastal radars. Sea clutter plays an important part at S-band and higher frequencies, but it is relatively unimportant at L-band. Practically all the observed short-range targets at L-band are due to radar returns from birds.

A sensitivity time control (STC) waveform generator is described that eliminates the bird returns and allows both manual and automatic systems to operate against bomber- and fighter-type aircraft in all regions on normal days without mapping.

In order to be effective in eliminating birds while still retaining coverage against aircraft, the STC must be tailored to the gain characteristic of the receiver. Since the range independence of the target rejection depends critically upon the waveform, the site personnel should not be allowed to change the waveform except to match it to a standard. The STC should be considered as a means of removing "point" targets on the basis of target radar cross section rather than as a means of removing all unwanted returns.

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## ELIMINATION OF A TYPE OF NATURAL CLUTTER
## IN L-BAND RADARS

### I. INTRODUCTION

For a number of years, radars – especially coastal radars – have been observed to display at short and medium ranges many targets that do not seem to coincide with any actual reflecting objects. A great many of these targets are not removed by moving target indicator (MTI) techniques, and there often appears to be little scan-to-scan coherence. The targets are usually so numerous in a coastal radar that the innermost portion of the plan position indicator (PPI), out to 20 or 30 nautical miles on radars of the types used in ADC, is not useful in surveillance or intercept direction either with a manual system using human operators or with an automatic data-processing system such as SAGE. In a manual system, the "hole" in the radar coverage may be officially recognized and rejected or it may be ignored unconsciously but, in either case, the operator finds it impossible to track any but very large aircraft in regions exhibiting these targets. Because the number of such targets is so large as to saturate the computer in SAGE, the central area of the PPI must be "mapped," that is, the data are rejected from these areas before they enter the computer. Although in a manual system the large aircraft may be tracked by their larger returns, this process is limited because of the restricted dynamic range of the phosphor used in the PPI scope.

Sensitivity time control (STC), which causes the gain to vary as a function of range in each interpulse interval in order to reject small targets, often improves the situation for both manual and automatic systems. If the gain is made too low at short ranges, however, the net result is frequently to remove the aircraft returns as well as the undesired targets, leaving the central portion of the PPI quite clean, but still preventing tracking through the area. It is therefore important that the shape and magnitude of the STC waveform be quite carefully controlled in order to conform to the range dependence of the targets to be removed.

### II. THE BIRD IDENTIFICATION EXPERIMENT

#### A. Target Characteristics

Figure 1 shows the PPI display of an L-band (1305 Mcps) coastal radar on Cape Cod on a typical day. The range marks are at a spacing of 10 n.mi., with full scale at 50 n.mi. This is a normal video presentation in which the land area of Cape Cod appears. The mainland of Massachusetts appears at a range of about 25 n.mi. to the west of the site, and cuts off at slightly greater ranges because of the radar horizon. The many targets visible over the water areas are the undesired targets under discussion. The ring at about 8 n.mi. is caused by large fixed targets at Provincetown, on the tip of the Cape, which are visible on the side and back lobes. Figure 2, taken within a few minutes of Fig. 1, shows the same area with MTI presentation. A great number of targets are still visible, although the land areas have been removed, which

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Fig. 1. PPI presentation of normal video from AN/FPS-3 radar at South Truro (10-n mi. range marks; full scale 50 n.mi.).



Fig. 2. PPI presentation of MTI video taken shortly after Fig. 1 under same conditions.

indicates that the MTI is functioning properly. In fact, the land areas appear as silhouettes in Fig. 2, since very few moving targets appear over them because of the finite subclutter capability of the radar.

This experiment was begun with an AN/FPS-3 radar whose lower beam, having a vertical beamwidth of approximately 3°, just "scrapes" the horizon at its lower 3-db point. The upper beam, of approximately 9°, is positioned just above the lower beam. The undesired targets were visible on the lower beam but were not observed on the upper beam. In later portions of the experiment, an AN/FPS-20 was used.

Questioning the operating and maintenance personnel at a radar site as to the identity of these targets usually elicits responses such as "AP" (anomalous propagation), "atmospherics," "sea clutter," "angels," or even "I don't know."

One of the most important considerations was to determine the identity of the targets and whether they were all of the same type. A very powerful tool in this effort was the coherent video out of the IF phase detector as viewed on the A-scope. The antenna was stopped and allowed to searchlight at an azimuth containing the undesired targets while the A-scope was viewed. Figure 3 shows sea clutter at short range, and two of the typical undesired targets at longer ranges. The range scale has been expanded so that it shows 0 to 20 n.mi. in order to show greater detail in the region viewed. The sea clutter is seen to have noisy amplitude characteristics. This photograph was taken under very windy conditions and is one of the very few
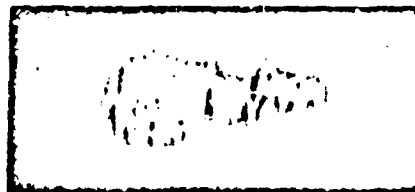


Fig. 3. A-scope presentation of coherent video (IF phase-detector output) from AN/FPS-20 at South Truro (full scale approximately 20 n.mi.).

observations of actual sea clutter during the entire year of this experiment. Even under these unusual conditions, sea clutter is visible only out to about 12 n.mi. Usually, no sea clutter at all is observed at this site. Investigation of the typical undesired targets shows that each is a discrete target having a pulse length equal to the transmitted pulse length — that is, each is essentially a point target. The coherent video varies in amplitude from pulse to pulse as the phase

changes because of change in range, which indicates that each is a moving target. From observation of the pulse shape on the A-scope and measurement of Doppler frequency shift using a gated pulse stretcher (boxcar) centered upon individual targets, it is apparent that each target has a discrete velocity that changes in a somewhat random manner, and that adjacent targets often have quite different radial velocities.

Measurement of the true Doppler frequency would be a measure of true radial velocity but, because of the low repetition rates of the radars used, the first blind speed is approximately 80 knots; measurement of speed is therefore ambiguous, with an ambiguity interval of about 40 knots. Measurement of apparent Doppler frequency and simultaneous rough measurement of range rate on the A-scope were used to resolve the speed ambiguity. By this means, it was determined that the range rate almost certainly did not exceed 90 knots, and that it was usually less than 50 or 60 knots. This has also been verified by measurement of elapsed time and distance traveled by these targets on scan-by-scan PPI "movies" (see Sec. II-G). Observations at various azimuths indicated that most of the targets were of the same type. They were observed to remain in the beam of the searchlighting antenna for as little as a few seconds, and sometimes for as long as several minutes. The scan-by-scan movies show that many of the individual targets are discernible for an hour or more, although usually they would not remain in a searchlighting beam for even an appreciable fraction of that time.

## B. Diurnal and Seasonal Variations

Having determined that the targets are mostly of the same type, the next procedure was to determine the diurnal and seasonal variations of their occurrence. The personnel at the site stated that most clutter of this type occurs during the summer months, but the exact variation was not documented by records. For a period of a year, beginning in December 1956, many days (and nights) have been spent observing the PPI scope on MTI presentation for diurnal variations, and many periodic and scan-by-scan photographs have been taken over 24-hour periods. The present data therefore show the diurnal variations approximately one day a week for a year.

In general, there are more of the targets during the summer months than during the winter. Except for certain periods in the spring and fall, there are usually more targets during daylight hours than during the night. Figure 4 shows the daytime distribution on a typical winter day. The region at an azimuth of 120° seems to be a preferred region that varies somewhat in azimuth and varies in range from 15 to 35 n.mi., although at times it extends beyond 50 n.mi. This region has been observed throughout the period of the experiment. Attempts have been made to find some surface phenomenon that might explain the preference, but the hydrographic



Fig. 4. PPI presentation of MTI video on a typical winter day (10-n.mi. range marks).
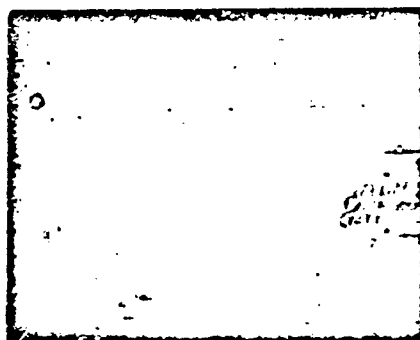
(a) 15 minutes after morning civil twilight. Tip of
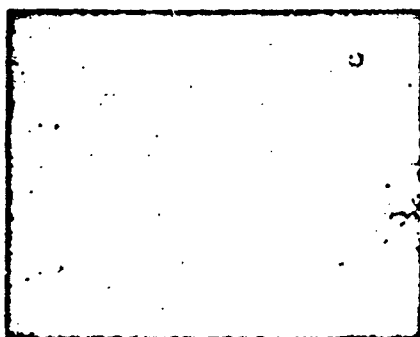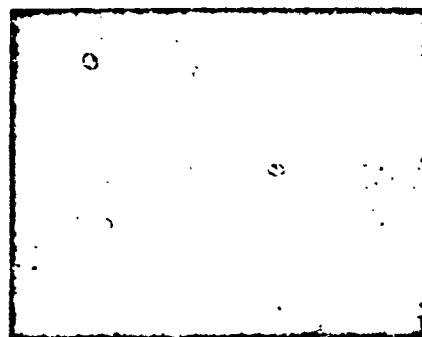Cape Cod outlined by moving targets.
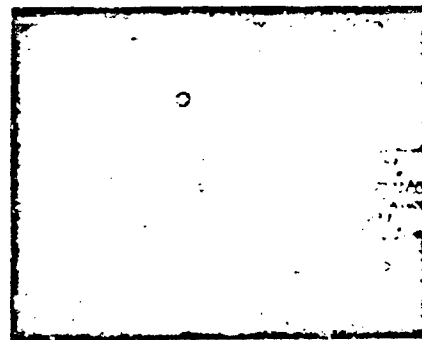
(b) 26 minutes before sunrise.

(c) 5 minutes before sunrise.

(d) 16 minutes after sunrise.

Fig. 5.  MTI displays on a normal winter day, (10-n.mi. range marks).

charts show 80 to 100 fathoms of water in the preferred region. Local pilots and fishermen state that the water is usually rougher in this region than in surrounding areas, probably because of interaction of opposing currents.

Figures 5(a) through 5(d) show a sequence of pictures at 21-minute intervals encompassing sunrise on 4 February 1957. On that date, morning twilight started at about 0648, 15 minutes before the first picture. In Fig. 5(a), the tip and "wrist" of the Cape are plainly outlined by the undesired targets. In Fig. 5(b), taken 21 minutes later, the outline is no longer visible, and targets are seen beyond 20 n.mi. at many azimuths. Figure 5(c) is 5 minutes before sunrise and shows even greater spread and density. Figure 5(d) is 16 minutes after sunrise and shows the continuing spread. Viewing this same period on the scan-by-scan movies shows that the targets that first appear at the shore of the Cape travel in approximately straight lines in their over-spreading of the scope. During the day, there is a general milling around, with usually a general drift component in the direction of the surface wind. In the evening, the trend is toward the Cape, but it is not so marked as during the morning outward rush.

Figure 6 shows a RAPPI display on a winter afternoon. The range is approximately 50 n.mi. full scale. The first 10 n.mi. are gated out in the FST-2. The tube used in the RAPPI has a phosphor of extremely long persistence, so that the tracks show the history of the targets. The tracks to the south are aircraft that use Nantucket as a turning point. The shorter tracks are the targets under discussion. The relative lengths of the tracks are a measure of the relative speeds. It is interesting to note the random direction and almost uniform speeds of the unde-sired targets.

In the spring, after the normal target density has reduced in the evening, the scope becomes overspread with a great number of targets with nearly uniform density, approaching from the south and heading toward the northeast, with their density reducing about midnight. In the fall, the timing is somewhat different. The targets appear somewhat later, continue until nearly dawn, and move in a general southward direction. Figure 7, taken in the fall, shows the type of distri-bution observed. The general direction of the targets is usually affected by the surface wind
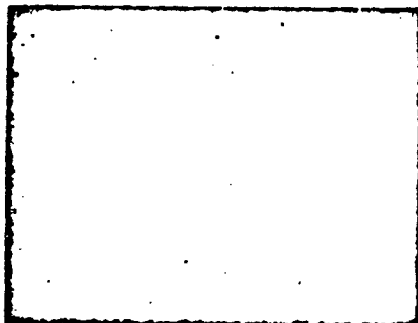
Fig. 6. RAPPI display of MTI video on a winter afternoon. Radar situated at center of "hole" slightly above center of picture.
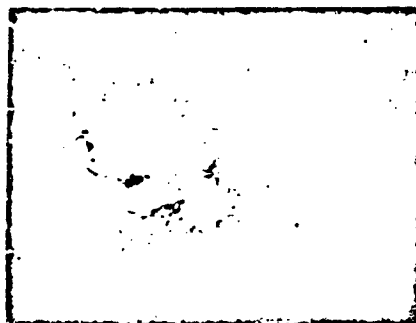
Fig. 7. MTI display of southbound targets on an autumn night (10-n.mi. range marks).

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direction, but their velocity is much greater than the wind. When this picture was taken, their velocity was between 35 and 65 knots when the surface wind was 16 knots. A wind profile up to 20,000 feet showed no winds at any altitude that would account for the motion. It should be noted that there are sectors to the east and west where there are very few targets. This is because the general motion is southward; targets at these azimuths have no radial velocity and are therefore rejected by the MTI circuitry. The few targets seen at these azimuths are due mostly to local targets traveling in or out.

## C. Possible Identifications

At this point, it is appropriate to consider what possible explanations might be advanced for these targets. The general class of targets of which these are one type has been labeled "angels" — radar returns from unknown or invisible targets.

### 1. Sea Clutter

The original hypothesis of the personnel at the site was that the echoes were sea clutter. The point-target, finite-lifetime and discrete-velocity properties, however, are inconsistent with sea clutter. In addition, there is not the proper correlation with wind direction and velocity. A visit to an ADC site equipped with both L-band and S-band radars of comparable sensitivities showed that, when the S-band radar was observing sea clutter out to 20 n.mi. or so, the L-band set showed only these point targets and no distributed sea clutter. Theoretical investigation of known sea-clutter observations made from aircraft indicates that, with the power and beamwidth of ADC radars, surface-mounted L-band sets should not be expected to observe sea clutter beyond a mile or so, while at higher frequencies it should be observable to greater ranges. This is because the grazing angle above which sea clutter is visible decreases with decrease in radar wavelength as well as with increase in wave height.

### 2. Weather

Some meteorologists believe that most "angels" are due to atmospheric inhomogeneities of one type or another. Theories have been propounded of atmospheric "bubbles" — regions of sharp dielectric-constant discontinuities, or vortices giving rise to reflections. The theories are not capable of predicting returns of the size observed. Such bubbles and vortices would be expected to move with the prevailing wind, and the observed random velocity changes and velocity differences of adjacent targets, as well as the large velocities relative to the winds, are not consistent with such hypotheses. Evidence concerning horizon of the targets under discussion indicates that they are usually at altitudes of less than a few hundred feet.

### 3. Insects

The meteorologists have done a great deal of their work at K-band, where the wavelength is comparable with insect dimensions, and there appears to be evidence that at least some of their targets are due to insect returns. Insects are in the Rayleigh region at L-band and should be negligible.

### 4. Birds

A fourth possible interpretation is that these targets are returns from birds. Reports of bird sightings with radars are numerous in the literature; some of these reports are listed in

the bibliography of Appendix A. Measurements performed by Air Force Cambridge Research Center (AFCRC) and at the M.I.T. Laboratory for Insulation Research in conjunction with Lincoln Laboratory projects on the DEW Line have indicated that a sea gull behaves as though he is a quart of water (blood) flying around. At the wavelength of this radar, a quart of water would have a cross section of the order of 0.01 square meter. This amount of water in a sphere, which is a shape possible to treat both analytically and experimentally, would have a size in the diffraction region for 1300 Mcps.
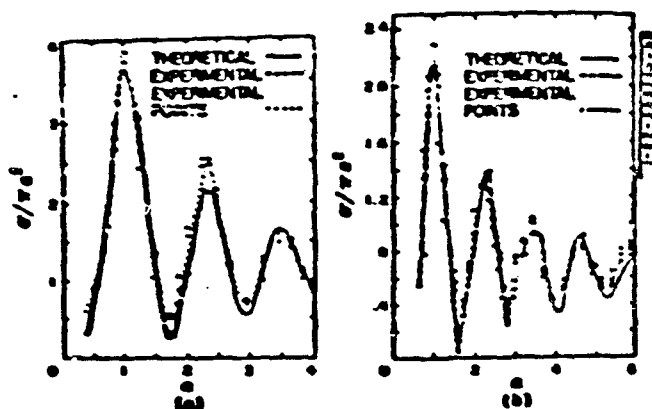


Fig. 8. Radar cross sections of (a) metal and (b) water sphere as a function of radar wavelength.

Figure 8 shows how the radar cross section for a sphere varies with wavelength. The horizontal scale is the ratio of circumference of the sphere to the wavelength of the radiation, and the vertical scale is the ratio of the radar cross section to the geometrical cross section. [The figures are from Aden, "Electromagnetic Scattering from Spheres with Sizes Comparable to the Wavelength," J. Appl. Phys. 22, 601 (1951).] When the circumference is equal to the wavelength, the "ground wave" traveling around the sphere just adds to the incident wave in such a way as to give maximum reflection. The peak comes at the same radius for a metal (conducting) sphere as for a distilled-water (dielectric) sphere. The solid curves are theoretical, but the points and dashed curves are experimental and match the theory quite well. The measurements were performed at Cruft Physics Laboratory of Harvard University. The quart of water mentioned would come at the first maximum – a cup of water having almost an order of magnitude greater cross section.

Of course, the bird is not a sphere, but most of the moisture is contained in the body. The AFCRC measurements indicate that the bird behaves more like a cone, the nose-on aspect being appreciably greater than the tail-on aspect. Because of the many compounds dissolved in the body fluids, a bird more nearly approaches a conducting object than a dielectric one.

Using a conservative estimate of $0.01 \text{ m}^2$ for the bird cross section, then with the known power, receiver noise figure, and beam pattern of the FPS-20 radar having the lower 3-db point

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of the antenna pattern on the horizon; a single sea gull on the horizon at 250 μsec (approximately 20 n.mi.) range should give a return approximately 36 db above receiver noise.

As an illustration of the reasonableness of this figure, consider that an F-86, having a cross section of about 1 m², is reliably visible to about 185 n.mi. (indicating about 3 db above noise). At 20 n.mi., a target of 0.00014 m² would give the same return. On this basis, the 0.01-m² target would be expected to give a return 22 db above noise at 20 n.mi. The 8-db discrepancy is not excessive, considering the qualitative nature of the cross-section estimates.

## D. Habits of Birds

As the experimental data were accumulated, it was felt wise to inquire into the habits of birds.[*] Professor Charles Blake, former Professor of Comparative Anatomy at M.I.T. and an avid bird watcher, spent some time at Lincoln Laboratory discussing the problem. It seems that the major portion of the bird life at Cape Cod in the winter consists of sea gulls and sea ducks which are comparable in size. During the summer, the gulls migrate to Northern New England and are replaced by smaller gulls and other birds. The gulls feed by day, and may range as far as 100 n.mi. to sea. Although they usually come ashore preceding and during inclement weather, they often sleep at sea in the winter when the water is warmer than the air. Their feeding habits are such that they tend to orbit individually over specific regions of the surface, each bird having almost a private range from which others are excluded, except when copious food supplies are available. During nesting seasons, they tend to come ashore regularly. The sea ducks feed both by day and by night, and may feed in flocks. Top speed of both gulls and ducks may be between 40 and 60 knots.

## E. Number of Targets

The pulse length of the FPS-20 corresponds to 1/2 mile of range, and at 20 n.mi. the horizontal beamwidth is about 1/2 mile. Therefore, a uniform distribution of four birds per square mile could completely blank the PPI, although a much smaller density would explain the observed patterns. This is not a very great density, and a traveler on or above the surface would not be apt to even notice the gulls in this density unless he were specifically looking for them. The tremendous number of targets on the PPI is due to the compression of thousands of square miles of the earth's surface onto a few square inches of scope face. Even during times of migration, the scope has not been observed to be completely blanked by the birds.

## F. Visual Correlation

On several occasions, low-altitude aircraft flights have been correlated with the radar observations. The distributions observed from the air have in each case been consistent with the radar patterns. Actual identification of an individual target is not so easy as it might at first appear. Because the aircraft is a bright target, it covers an area on the PPI almost as large as the viewing region of the airborne observer. As mentioned earlier, since the lifetime of the targets is variable, probably because of the descent of the birds to feed, it is impossible to predict that a

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[*] E.g., Lincoln and Pines, "Migration of Birds," U.S. Fish and Wildlife Service, Circular No. 16 (1950).

particular bird will be visible to the observer. Obviously, the observer will miss some of the birds because they are rather small. They may not be visible from the 500-foot altitude when they are on the surface with their wings folded. There have been several individual target correlations, however, and the statistics of the observed bird distributions are quite good in their correlation with the observed radar-target distributions.

## G. Scan-by-Scan Pictures

The radars used in this experiment have an azimuth scan rate of 12 seconds per revolution. Scan-by-scan movies have been made by exposing successive scans on successive frames of 35-mm movie film. When these films are viewed on a moving picture projector to speed up the time scale, persistence of vision allows examination of target motions even when the number of targets is so large as to confuse a scope observer operating on a real-time scale. This means has been used to determine that the diurnal and seasonal variations of these targets correspond to observed habits of birds, awakening and flying out to sea during morning twilight and returning during evening twilight, although they sometimes seem to just sit down on the surface in the evening. The tremendous rush during the morning seems to be due to the fact that they are all very hungry. During the day, there is a general milling about in search of food, and the evening return is more of a straggling operation.

The northeastward flow in the late evening during the spring corresponds nicely with the observed habits of land birds, which are known to feed and rest during the day and to start their migratory flights in the evening. The direction of flow coincides with the direct path from Long Island, Rhode Island and Cape Cod toward Nova Scotia. If the birds are to make that trip (about 200 miles) during the night when the danger from predatory birds is minimum, then they would be expected to leave Cape Cod before midnight, which correlates with the diminishing in observed migrating targets.

The southward flow in the fall continues until dawn, which is again consistent with the fact that migrating birds reach their resting and feeding grounds at an appropriate time.

Computation of radar cross section indicates that the birds are horizon-limited — that is, they would be visible in free space to a range much greater than that at which they are observed to cut off on the PPI. The cutoff at 10 a.m. corresponds to a maximum altitude of the birds of less than 300 feet. This is in agreement with the observations from low-altitude planes, in which birds are seldom seen at the same altitude as the plane. On days of anomalous propagation, which occur quite often in the summer and occasionally in the winter, when surface targets are visible out to much greater ranges than normal, the birds are often seen out to 100 a.mi., or even more.

It is evident from the observations made in the course of this experiment that a high-power radar, coupled with occasional airborne identification as to type of birds, would become a very strong tool in the hands of an ornithologist.

Of course, there are some targets on the PPI that are not due to birds. Among the most obvious are aircraft and weather. Figure 9 shows a typical weather display. It should be noted that the weather is more of a distributed target, not showing the point characteristics that birds have. Observation of the scan-by-scan movies indicates the general mass motions of clouds or

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storms, but the mass is composed of flickering spots rather than exhibiting scan-to-scan coherence as the birds do. In this regard, it has been noted that the number of bird targets decreases in times of inclement weather. The road to the radar site leads past several town dumps and, on the bad days when there are a lot of scavenging birds at the dumps, there are very few bird targets over the water.

Surface vessels such as fishing boats and pleasure craft are present in considerable numbers during the summer months. Because of the radar's relatively low cutoff velocity, these are not removed completely by the MTI circuitry.



Fig. 9. Typical MTI weather display (10-n.mi. range marks). Land areas appear in soft outline because of finite subclutter capability of radar.

### H. Other Sites

Visits have been made to various ADC sites, both coastal and inland, and PPI photographs have been obtained. The coastal sites show distributions of targets similar to those described above. The inland sites show only a few targets that might be identified as birds. This is probably due to the fact that MTI radars have limited subclutter visibility, and the birds are suppressed by the land clutter, as in Fig. 7. At mountainous sites, some bird returns have been observed in regions where valleys exist and the ground clutter is shielded from the radar site by intervening hills, but the airborne birds are still visible.

### I. Summary of the Bird Problem

On the basis of the calculations and the experimental results, it is apparent that most of the overwater targets observed at coastal sites are due to radar returns from birds, and that the bird problem is one of a distribution of individual point targets with discrete velocities. The number of targets is less in the winter than in the summer at Cape Cod, but this characteristic is dependent upon the latitude of the site and the consequent climatic conditions. All radar sites should have this problem to some degree, although sites exhibiting considerable ground clutter have the MTI sensitivity in the regions of clutter so reduced that they will observe birds only occasionally. For the usual ADC radar, the bird velocities extend almost to the first blind speed, so that it is impossible to discriminate against them in the radar on the basis of velocity.

## III. SOLUTION OF THE BIRD PROBLEM

### A. Removal of Bird Returns by STC (see also Appendix B)

Analysis of propagation principles indicates (the well-known "radar equation") that the radar power returned from any target is proportional to the radar cross section of the target and inversely proportional to the fourth power of the range to the target. Therefore, for a target at a given range, the received power is proportional to the radar cross section. Since the sea gull

(or duck) is approximately 12 db smaller than an F-86 (nose-on) which is, in turn, at least 10 or 12 db smaller than a B-50, it is feasible to remove bird returns on the basis of target size. An approach to this method has been in existence for years in the form of STC on many radars. The traditional STC circuit, using a single capacitor discharge, does not provide a gain variation that allows setting of a target cross section threshold over an extended-range region. It may be made acceptable for a particular range segment, but it usually introduces a hole at shorter ranges. It must be gated off at longer ranges to prevent excessive reduction of sensitivity at long ranges. The ideal STC gives a receiver voltage gain that varies as $R^2$, since the received voltage is proportional to the square root of the received power.

In order to determine the correct STC waveform to provide the proper gain variation over the region troubled by birds, Group 42 measured the gain characteristic of the FPS-20 IF preamplifier and determined that, in order to cause the voltage gain to have the desired $R^2$ characteristic, the applied bias voltage must have a DC component (determined by the radar parameters and the size of the targets to be rejected) and a time-varying component proportional to the logarithm of time after the transmitted pulse (for ranges where birds exist) which is not changed in amplitude or shape during any operational adjustments.

It is extremely important that the operational adjustments consist only of variation of the DC component to accommodate to the size of targets expected, since change in amplitude or shape of the time-varying component will cause birds to show up at some ranges, or will introduce holes in coverage at some ranges.

## B. The Lincoln Laboratory STC Unit

A self-contained STC unit incorporating the principles discussed above has been built by Group 42 and installed at South Truro. The unit is described in Appendix D. Four months of operational experience indicate[*] that it has almost completely eliminated mapping on normal days (those days without appreciable weather returns) and has allowed tracking of aircraft in regions that in the past were normally mapped because of birds. Mapping is the process that removes regions containing an excessive number of targets before radar data are fed to the computer, in order that the computer target-handling capacity will not be saturated.

The unit is checked and installed by both military and civilian technicians who are given only short verbal instructions. During the four months of operation, the only maintenance that has been required has been due to tube failure.

Figure 10 shows an MTI PPI photograph on a normal day without STC. Figure 11 shows an MTI PPI photograph taken 24 seconds before Fig. 10, the only difference being that the STC voltage had been applied to reject a target 30 db above noise at 20 n.mi. This setting rejects targets of the same cross section from about 5 to 60 n.mi. It is seen that most of the targets have been removed. The targets remaining to the south and southwest between 15 and 30 n.mi. are targets just south of Cape Cod. Investigation by means of scan-by-scan photographs shows them to be clusters of birds feeding near the shore. It is to be noted that these targets appear also in Fig. 10, and that no new targets have been introduced by addition of STC. The targets remaining near

[*] Memorandum from L.C. Wilber, Group 21 (7 January 1958).
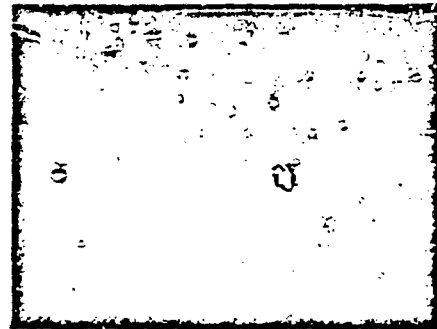
Fig. 10. Typical MTI display without STC.



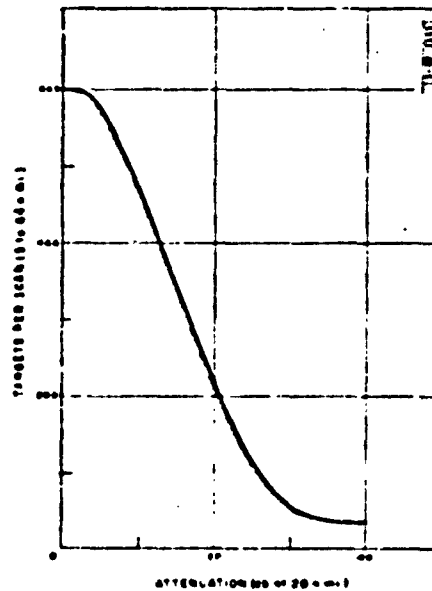Fig. 11. MTI display under same conditions as Fig. 10 but with addition of Lincoln Laboratory STC.



Fig. 12. Usual number of targets appearing at AN FST-2 output as a function of attenuation at 20 n.mi. (FST-2 saturates at 600 targets).

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10 n.mi. at 310° to 320° are birds feeding in clusters off Provincetown. The rest of the targets are aircraft.

Figure 12 shows a plot of the usual number of targets appearing at the output of the FST-2 in the region from 5 to 64 n.mi. as a function of attenuation at 20 n.mi., using the STC unit. The targets remaining beyond 30-db attenuation are real aircraft, ships and clusters of birds.

It should be re-emphasized that introduction of this STC has allowed complete removal of mapping on normal days without saturating the telephone-line capacity from South Truro, and that it has simultaneously retained the capability against bomber-type and fighter-type aircraft, except for high-angle coverage on fighters as discussed below.

## C. STC at Video

The manufacturer of the FPS-20 provides, as a field modification, an instantaneous sensitivity time control (ISTC)[*] that is essentially a negative pedestal applied to MTI video after cancellation. If the waveform is correct, then such a scheme would be expected to give (in most regions) equivalent operation to STC applied at IF, as described in this report. Some additional requirements are placed upon the waveform when STC is applied at MTI video.

Because of the limited subclutter visibility of a scanning MTI radar, targets are suppressed in regions of ground clutter (see also Appendix C). Large aircraft targets may give very small video returns, and birds are eliminated altogether. In this case, it is necessary to remove the negative pedestal to a degree determined by the size of fixed clutter present. The ISTC does this by means of mixing in a clutter profile obtained from a logarithmic receiver.

Since the IF signal fed to the coherent phase detector (to provide bipolar video for the cancellation unit) is amplitude-limited, there is no information in the MTI video as to the size of targets that exceed the limit level. For inland sites, where there is usually ground clutter in the first several miles, birds probably never exceed the limit level. At a coastal site, however, close-in birds may give radar returns in excess of the limit level at the phase detector. In this case, it is impossible to remove them at MTI video without simultaneously removing desired targets.

The application of STC at MTI video has the additional disadvantage that it neglects the normal video channel. In most ADC radars, the normal video presentation is used whenever possible because it does not have the loss in sensitivity (due to blind speeds) exhibited by MTI. Application at IF allows one unit to provide STC for both normal video and MTI channels.

There appears to be no advantage to application at MTI video, and there are several disadvantages.

## D. STC and Clutter Effects on High-Angle Coverage

Unfortunately, the reduction of gain at short ranges reduces the high-angle coverage capabilities of the radar, as discussed in more detail in Appendix C. The reduction is not significant for large targets such as bombers, but it is significant for fighter aircraft. In the SAGE concept, since fighters are tracked by IFF, the reduction in high-angle coverage is acceptable. If it were

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[*] Memorandum from J. K. Martin and J.C. Nolan, Bendix Radio Division (15 July 1957).

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decided to utilize radar returns for the tracking of fighters, then it would be desirable to minimize the high-angle loss by means of an STC maximum-range gate, as discussed in Appendices C and D and included in the Lincoln Laboratory unit.

South Truro is a special case in that there is very little ground clutter at short ranges at any azimuth. In most seacoast radars, there is very little ground clutter on the seaward side. In regions of large ground clutter, however, even large aircraft targets are suppressed in the MTI video because of the finite subclutter capabilities. Thus, high-angle coverage, which depends upon seeing a target on the "skirt" of the beam (the so-called cosecant-squared region), is reduced by ground clutter in an MTI radar, even though the ground clutter cancels well and does not introduce false targets. ("Product Improvement Proposal, AN/FPS-20 T-2690-S," Bendix Radio Division, pp. 1 to 11, gives a qualitative discussion of this effect.) The important relationship between STC and ground clutter is that, if the ground clutter is large enough to suppress bird targets, which it is observed to do usually, then introduction of an STC gain reduction that would just suppress a bird target at a particular clutter-free range will not reduce the ground clutter sufficiently to have an appreciable effect upon the subclutter visibility. Thus, introduction of bird-removing STC applied in the IF preamplifier before limiting does not introduce additional suppression of high-angle coverage in ground-clutter regions.

High-angle coverage could be regained by return to the concept of two beams, where the lower beam would include STC to remove birds and MTI to remove ground clutter, and the upper beam would not observe either birds or ground clutter because of their low altitude.

Other researches have led to the proposal of introduction of a logarithmic receiver to combat noisy weather and some types of chaff. Existing logarithmic receivers will not function properly with the large gain variations necessary for STC. It is therefore desirable to separate the IF for the normal and MTI receivers from that to the logarithmic receiver quite early in the amplifier chain before limiting occurs on any targets of interest. In such a case, the STC should be applied to the IF for the normal and MTI receivers after the branching takes place.

## IV. RECOMMENDATION

On the basis of the information discussed in this report, it is recommended that all seacoast radars (or the lower beam of multiple-beam seacoast radars) and all other L-band or higher-frequency radars experiencing difficulty with bird echoes should be equipped with STC circuitry applied to the IF preamplifier. The STC waveform should cause the receiver voltage gain to vary as $R^2$ and to have attenuation appropriate to the site and the radar. The STC in a single-beam radar should have an adjustable cutoff range to optimize high-angle coverage. The traditional single RC discharge network commonly used for STC does not provide acceptable operation.

It is important to remember that STC has its optimum utility in removal of individual point targets. If ground clutter, weather or other distributed targets — or targets comparable in size to the desired targets — are to be removed, other techniques should be used.

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## APPENDIX A
### BIBLIOGRAPHY ON RADAR BIRD SIGHTINGS

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## APPENDIX B
## DESIGN OF STC UNIT

The controlled stages of the IF preamplifier of the AN/FPS-20 are two 5654/6AK5W amplifiers. In order to apply a time-varying gain-control voltage, it is necessary to replace two resistors in the gain-control bus decoupling network with 30-Mcps self-resonant chokes. The gain characteristic has been measured a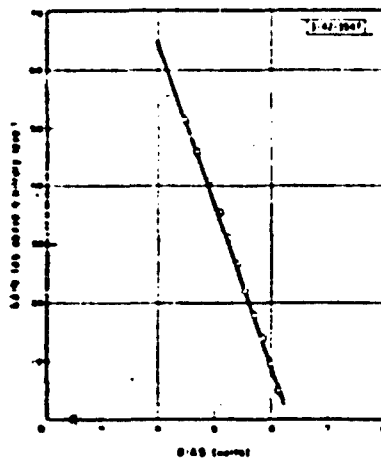nd is presented in Fig. B-1, where the abscissas are bias voltage and the ordinates are gain in db above an arbitrary level. It is seen that the gain in db varies linearly with bias-voltage change over the region in which the preamplifier is usually operated. This means that the voltage gain varies as an exponential function of the bias-voltage increment in this region:

$$A = Ke^{mB} \qquad (1)$$

where A is the voltage gain, K is a constant, m is determined by the slope in Fig. B-1, and B is the bias voltage (negative).

The ideal STC maintains the output voltage constant for a target of a given cross section, regardless of range. The radar equation states that the received voltage varies as:



Fig. B-1. Gain characteristic of IF preamplifier of AN/FPS-20.

$$V_r = D \frac{\sqrt{\sigma}}{R^2} \qquad (2)$$

where $V_r$ is the received voltage, D is a constant determined by the radar parameters, $\sigma$ is the target radar cross section, and R is the range to the target.

The receiver output voltage is

$$V_o = AV_r = AD \frac{\sqrt{\sigma}}{R^2} \qquad (3)$$

where A is the receiver voltage gain, and $V_o$ is to be held constant for a given $\sigma$. Solving (3) for A gives

$$A = \frac{V_o}{D} \frac{R^2}{\sqrt{\sigma}} \qquad (4)$$

Equation (4) is to be equated to Eq. (1) for the FPS-20:

$$\frac{V_o R^2}{D\sqrt{\sigma}} = Ke^{mB} \qquad (5)$$

Taking the natural logarithm of both sides gives, after rearranging terms,

$$B = \frac{1}{m} \ln \frac{V_o}{DK} - \frac{1}{2m} \ln \sigma + \frac{2}{m} \ln R \qquad (6)$$

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Equation (6) shows that the desired bias voltage contains a DC term that depends upon radar parameters, a DC term that depends upon the gain characteristic of the controlled stages and upon the desired target cross section, and a time-varying term whose amplitude depends upon the gain characteristic and whose shape varies as the logarithm of range (or logarithm of time after the transmitted pulse).

A comparison of the logarithmic curve with RC discharges of various time constants shows that it is not possible to match it accurately over a large enough range interval to remove it effectively. However, the addition of two capacitor discharges having discharge time constants of 40 and 600 μsec, respectively, produces an acceptable STC voltage for the region from 30 to 1200 μsec. Fig. B-2 is a plot of the two capacitor discharges, together with the desired logarithmic curve. The points shown are from addition of the two discharge curves. At very short ranges (extremely low receiver gain), the receiver characteristic departs from the exponential form, and TR recovery also changes sensitivity; hence, the gain departs from the desired gain somewhat more than Fig. B-2 indicates.

As discussed in Appendix C, the departure of the synthesized curve beyond 1200 μsec is not serious, since it is not desirable to apply STC at that range in any case. Investigation is continuing as to the general applicability of the linear db gain vs bias-voltage characteristic, in order to determine whether this shape in fact applies to other IF amplifiers.
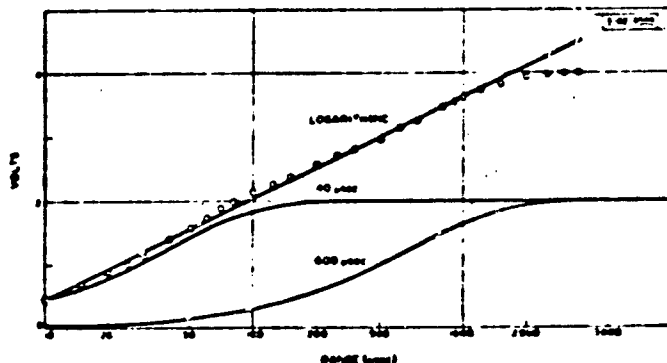


Fig. B-2. Addition of two capacitor discharges to approximate a logarithmic curve. The indicated points are the result of adding the two curves, and the straight line is the logarithm. Since preamplifier gain sensitivity is about 28 db per volt of bias, departure from the desired logarithm by 0.1 volt causes a departure in gain of 2.8 db. In operation, a fixed DC is added to this curve to determine target size.
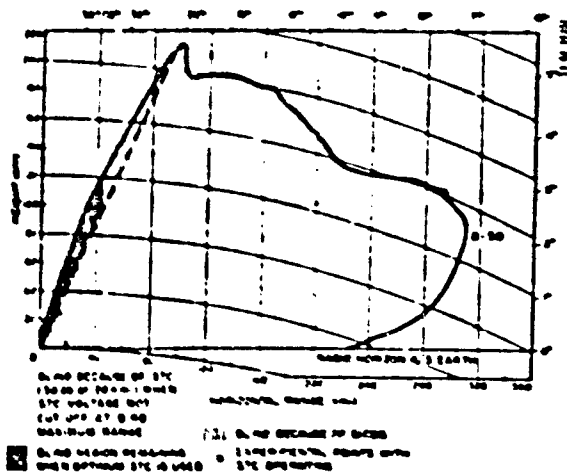
Fig. C-1. Approximate coverage diagram for a B-50, showing effects of birds and STC.



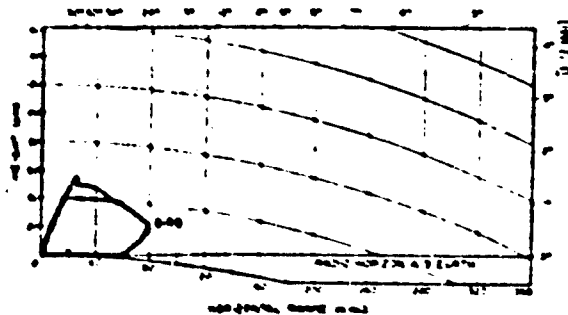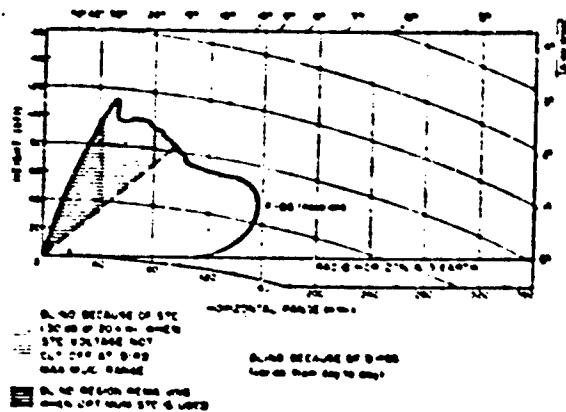Fig. C-2. Approximate coverage diagram for an F-86, showing effects of birds and STC.



Fig. C-3. Approximate coverage diagram for a single bird.

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## APPENDIX C
## HIGH-ANGLE COVERAGE AS AFFECTED BY STC

Figure C-1 shows the approximate coverage diagram for a B-50. The solid curve is the coverage expected in the absence of birds or ground clutter. The region shown vertically shaded is that which would be lost because of birds on an average day. On days of anomalous propagation, the birds are often visible to 100 n.mi., in which case the vertically shaded region would have to be extended accordingly. On days of extremely anomalous propagation, birds have been observed to be visible even farther. In order for the extreme radar visibility to occur, it is necessary that the radar energy be trapped in a waveguide-like condition, in which case the signal strength falls less rapidly than $h^{-4}$. On such a day, STC may give some improvement, but no "clean" solution is readily apparent, since the ducting is almost certain to vary as a function of azimuth, and the STC characteristic would have to vary in conformity with it in order to remove the birds completely.

In order to determine the effect of STC upon the coverage, one first determines the range at which the target being rejected falls below the detection threshold. In the case of rejection of targets 30 db above noise at 20 n.mi., this range is approximately 95 n.mi. The coverage with STC is then determined by drawing a dashed line from the expected coverage curve at this range to the origin, as in Fig. C-1. The region lost by application of STC is indicated by horizontal shading, and the region lost either with or without STC is shown as double-shaded. For the aircraft under consideration, the net effect of STC is to recover the region shown only vertically shaded, without adding any loss that would not already exist because of birds in the absence of STC.

Figure C-2 shows the case of a fighter (F-86), in which the additional loss due to application of STC beyond the range to which birds are visible (the bird horizon) is appreciable. For the present SAGE concept, this rather serious coverage loss is acceptable because fighters are tracked by means of IFF. An increase in radar coverage for fighters r ay be accomplished by means of a gate that turns off the STC action beyond the bird horizon and is adjustable to match the STC maximum range to the bird horizon for the particular day and anomalous propagation conditions.

When the STC is thus gated off at the bird horizon, no coverage is lost due to STC that was not already missing because of birds; instead, low-angle coverage is increased even in the presence of birds.

Figure C-3 shows the expected coverage diagram for a bird target 12 db below an F-86 in cross section. Since no coverage is seen at 95 n.mi., the equivalent of the dashed lines in Figs. B-1 and B-2 removes the entire coverage, as expected. In fact, STC of 26-db attenuation at 20 n.mi. would remove the whole diagram. The difference between 26 and 30 db is due to the qualitative nature of the cross-section estimates.

Since the birds are primarily at very low altitudes, one might expect that as they approach the site they move up into a different region of the antenna-gain pattern. One would then be tempted to tailor the STC to allow for this second-order variation in received signal. Since the

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birds are at very low angles, they are in regions where there is appreciable lobing of the antenna pattern caused by reflections of energy from the earth's surface. This lobing varies as a function of azimuth because of variations in terrain. As mentioned in Sec. III-C with respect to clutter profiles, matching of control waveforms to azimuth variations usually is not feasible at an operating site, and the second-order improvement would not justify the great increase in complexity.

## APPENDIX D
### EXCERPTS FROM STC INSTRUCTION MANUAL

**1. DESCRIPTION OF STC UNIT**

The Lincoln Laboratory STC unit (Fig. D-1) is a self-contained unit that supplies STC and also replaces the manual-gain control provided with the AN/FPS-26. The STC unit is comprised of nine sections (Figs. D-2 and D-3).

**A. Trigger Standardizer**

The trigger standardizer consists of tube V1 and pulse transformer T1. The first stage of V1 couples the system trigger to the blocking oscillator (second section of V1) and isolates the blocking oscillator from the input circuit. The blocking oscillator converts the system trigger
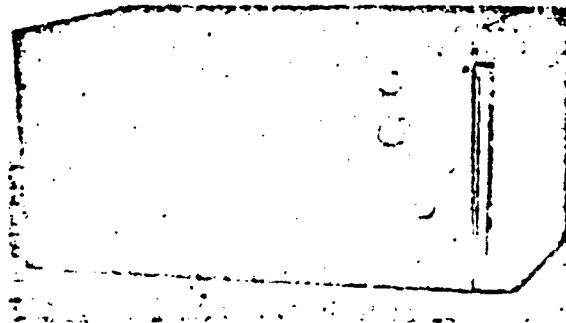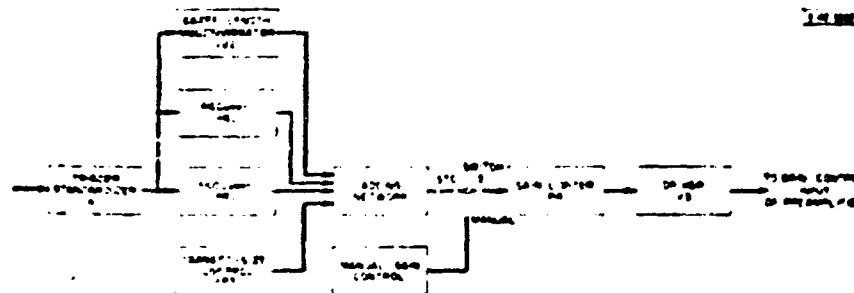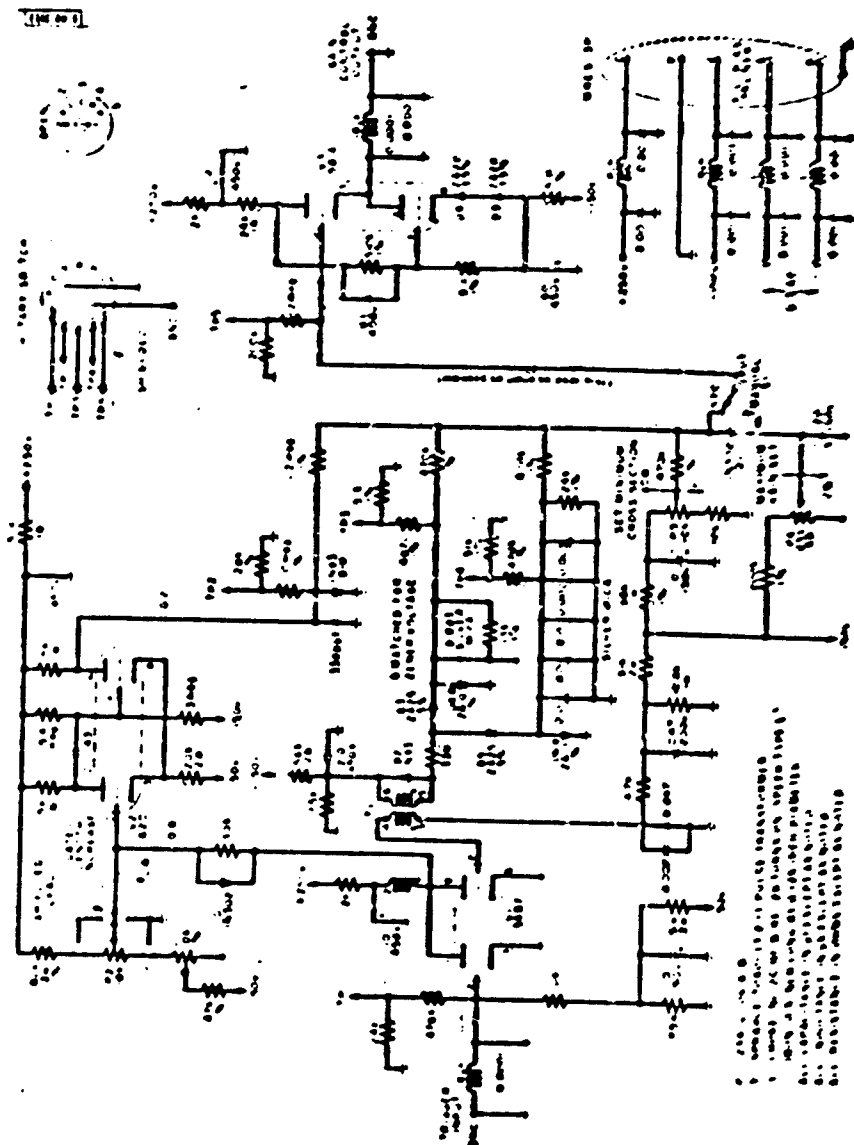


Fig. D-1. Lincoln Laboratory STC unit.



Fig. D-2. Block diagram of STC unit.

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to a pulse of proper voltage, shape and impedance level to charge the STC capacitors and to trigger the gate-length multivibrator V2.

The pulse length of the blocking oscillator is approximately 7 µsec as determined by the capacitance (0.022 and 0.047 µf) on terminal 3 of T5. (The transformer T5 is such that only this grid-circuit capacitance need be adjusted for proper pulse length.)

The trigger for V2 is taken from terminal 1 of T1, and the STC capacitors are charged from terminals 5-6 of T1. The 1N93 (D2) across 5-6 clips any positive overshoot that may occur, thus insuring proper charging of the STC capacitors.

**B. Target-Size Control**

The target-size control P3 regulates a DC voltage that determines the size of the target to be rejected.

**C. Gate-Length Multivibrator**

The gate length of the multivibrator is controlled by a DC voltage that is determined by P2. To insure proper triggering by the negative pulse from terminal 1 of T1, a 1N302 (D1) is placed across the 10-kilohm resistor. This diode reduces the charging time of the capacitor, thus giving a fast rise time.

Potentiometer P1 is an internal adjustment to obtain the proper variation in gate length when, because of a new tube or aging of components, the gate length is not correct (250 to 1400 µsec), or when free running occurs at the extremes of the gate-length potentiometer P2.

The 1N93 (D10) clamps the multivibrator pulse to the proper potential during the STC interval.

**D. Time Constants**

The 40- and 600-µsec time constants are charged through the 25-volt zener diodes D3 and D5, which maintain a low impedance for charging the STC capacitors while maintaining a high impedance on discharge of the capacitors.

The bias on D3 and D5, developed by the 46- and the 7.5-kilohm resistor and applied through terminals 5-6 of T1, is to maintain the diodes nonconducting between charging pulses.

The zener diodes D4 and D6 govern the maximum voltage to which the capacitors are charged (approximately -10 volts).

> Note: For proper STC operation, both time constants must be
> present. No attempt should be made to change the wave
> shape. If failure occurs, components may be replaced
> but not changed in value.

**E. Adding Network**

The adding network consists of a series resistance in each section. (40 µsec time constant: 470 kilohms; 600 µsec time constant: 470 kilohms; multivibrator gate: 1.2 megohms; target size: 470 kilohms.)

### F. Gain Limiter

It is necessary to limit the minimum bias (thus limiting maximum gain) in order that noise at long ranges will not exceed the threshold level in the data processor. Potentiometer P4, in conjunction with diode D7, accomplishes this function.

### G. Driver

The driver V3 is a "White" cathode follower that has an AC output impedance of 30 ohms. This is necessary to preserve the wave shape in the presence of the capacitive loading due to the decoupling network in the preamplifier bias circuitry.

### H. Manual-Gain Control

Manual gain is accomplished by setting S1 to manual and adjusting potentiometer P4 for the desired level.

## III. OPERATION OF STC UNIT

More complete descriptions of the STC unit, as well as installation and operating instructions, will be published in a forthcoming Lincoln Manual.

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